UNIT 1

MECHANICAL ENGINEERS & MECHANICAL ENGINEERING

Special Terms

Aerospace Industry: The industry concerned with the design and manufacture of aircraft, rockets, missiles, spacecraft, etc., that operate in aerospace.

Automotive: A field pertaining to the design, operation, manufacture, or sale of automobiles.

Automobile: (Motor vehicle) a road vehicle powered by a petrol engine or diesel engine.

Energy: The capacity of a body for doing work.

Engine: A prime mover; a machine in which power is applied to do work, often in the form of converting heat energy into mechanical work.

Engineering: The application of scientific principles to practical ends. An engineer is a member of the engineering profession, though the term also refers to people who operate or maintain certain kinds of equipment - a locomotive engineer on a railroad for example. In the latter use, the person referred to is a highly trained technician rather than a professional engineer.

Heat exchanger: A device for transferring heat from one medium to another, often through metal walls, usually to extract heat from a medium flowing between two surfaces.

Industrial Engineering: The subdivision of mechanical engineering that deals with the use of machines in industrial or manufacturing processes.

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Lubrication: The distribution of a lubricant between moving surfaces in contact to reduce the friction between them.

Machine: An apparatus consisting of an assemblage of parts, some fixed and some movable, by which mechanical power is applied at one point to transmit a force or motion at another point.

Mechanical Engineering: The branch of engineering dealing primarily with the design, production and operation of mechanisms and mechanical contrivances including prime movers, vehicles and general engineering products.

Mechanism: A system of mutually adapted parts working together which may not, however, constitute a complete machine.

Motor vehicle: (automobile) A road vehicle powered by a petrol engine or diesel engine.

Plant: All the machinery requisite for carrying on the business in a factory.

Power: The rate of doing work.

Steam engines: Engines in which the motive power is supplied by the elasticity and expansion or rapid condensation of steam.

Tool: Any implement by which mechanical operations are performed (whether by hand or machine) such as those used for forming and cutting.

Vibration: A repetition of some value of velocity in an arbitrarily selected particle in a mechanism.

Mechanical Engineers and Mechanical Engineering

The history of mechanical engineering can be traced directly to the ancient world, to the designers and inventors of the first mechanisms, which were powered by human or animal labor, water or wind energy, or a combination of these. The words "engine" and "ingenious" are derived from the same Latin root, "ingenerate" meaning "to create". The early English verb engine meant "to contrive". Thus the early engineers were the people who contrived (i.e. invented) new things. The invention of the steam engine in the latter part of the 18th century provided a key source of power for the

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Industrial Revolution and gave enormous impetus to the development of machinery of all types. As a result, a new major classification of engineering dealing with tools and machines, namely mechanical engineering, received formal recognition in 1847. Today's mechanical engineer is heavily involved in the development and use of new materials and technologies, and especially in computer aided engineering. A rapidly growing field for mechanical engineers is environmental control, comprising the development of machines and processes that will produce fewer pollutants as well as the development of new equipment and techniques to reduce or remove existing pollution. Although mechanical engineers may occasionally work alone on a small project, they are more likely to be working on large, multi-disciplinary projects, liaising with specialists from other areas. In almost every sphere of modern life, from the air conditioned office or home to the modern industrial plant or mode of transport, one sees the work of mechanical engineers who continue to develop and apply new knowledge and technology to improve the quality of life for society as a whole.

Mechanical Engineers play the main role in the design of all products and systems essential to everyday modern life-from home appliances, sports equipment and motor vehicles, to satellites, wheelchairs, airplanes, robots, solar panels, fuel cells, industrial equipment and environmental control systems. They are the designers of the mechanical, thermal and fluid flow related aspects of all such systems, including computer and feedback control of complex systems. In fact, mechanical engineers play a role in designing most of the things that people use. Look around you and you'll see their contributions everywhere. Design of these products involves a broad, basic education and significant knowledge of how to apply, interface and use computers in modern engineering systems. Mechanical engineers work in almost every technical field imaginable, including aerospace, automotive, biomedical engineering, computer aided design, energy and environmental systems. Indeed, a Mechanical Engineering (M.E.) education is the broadest of all engineering disciplines, with the widest applicability and most flexibility in terms of career paths. Mechanical engineering education involves learning how to creatively apply a strong scientific and mathematical basis to the design of safe, reliable, environmentally sound,

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and cost effective systems. Teamwork, communication skills and knowledge of how to apply and use modern computer simulations and control systems are important skills to all Mechanical Engineers. At the higher degree level, Mechanical Engineers perform the basic research needed to advance knowledge in the engineering sciences. The education of a Mechanical Engineer is very broad and focuses on the skills needed to be an effective problem solver. Many students combine the broad technical knowledge gained in their undergraduate M.E. studies with graduate study in M.E. Some M.E. students combine their M.E. knowledge with other technical disciplines such as Patent law, Business development, Research and Consultancy.

Four functions of the mechanical engineer can be cited:

- Understanding and dealing with the bases of mechanical science. These include dynamics, concerning the relation between forces and motion, such as in vibration; automatic control; thermodynamics, dealing with the relations among the various forms of heat, energy, and power; fluid flow; heat transfer; lubrication; and properties of materials.
- The sequence of research, design, and development. This function attempts to bring about the changes necessary to meet present and future needs. Such work requires a clear understanding of mechanical science, an ability to analyze a complex system into its basic factors, and the originality to synthesize and invent.
- The production of products and power, which embraces planning operations, and maintenance. To produce the maximum value with the minimum investment and cost while maintaining or enhancing long term viability and reputation of the enterprise.
- The coordinating function of the mechanical engineer, including management, consulting, and in some cases, marketing.

In the above functions there is a long continuing trend towards the use of scientific methods. Operations research, value engineering, and PABLA (problem analysis by logical approach) are typical titles of such rationalized approaches. Creativity, the ability to take the important and unexpected step that opens up new solutions remains in mechanical engineering, as elsewhere, largely a personal and spontaneous characteristic.

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3-alternative energy sources
4-biomedical engineering
5-business development
6-communication skills
7-computer aided engineering (CAE)
8-consultancy
9-contrive
10-enterprise
11-environmental
12-fuel cells
13-home appliances
14-hypersonic
15-impetus
16-industrial revolutions
17-interface
18-inventors
19-liaising
20-magnetic-levitation trains
21-maintenance
22-manufacturing processes
23-multi-disciplinary
24-patent law
25-physicians
26-pollutants
27-radioactive waste removal
28-shovel
29-simulations
30-solar panels
31-sports equipment
32-supersonic
33-synthesize
34-therapists
35-undergraduate
36-wind generated power

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UNIT 2
ENGINEERING DESIGN PROCESS

Special Terms

Brainstorming: A group problem-solving technique that involves the spontaneous contribution of ideas from all members of the group; *also* the mulling over of ideas by one or more individuals in an attempt to devise or find a solution to a problem.

Competent: (a) Having requisite or adequate ability or qualities. (b) Having the capacity to function or develop in a particular way.

Durability: Able to exist for a long time without significant deterioration.

Engineer: One qualified to design, construct or supervise the execution of mechanical, electrical, hydraulic, pneumatic, electronic and other devices, public and military works, etc.

Inefficient: Not producing the effect intended or desired.

Management: (a) Conducting or supervising of something (as a business). (b) Judicious use of means to accomplish an end. (c) The collective body of those who manage or direct an enterprise.

Monotonous: Tediously uniform or unvarying.

Productive: Having the quality or power of producing especially in abundance.

Reverse engineering: To disassemble and examine or analyze in detail (as a product or device) to discover the concepts involved in manufacture usually in order to produce something similar.

Sift: (a) To separate or separate out by or as if by putting through a sieve. (b) To go through especially to sort out what is useful or valuable —

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often used with *through*.

Supervisor: An administrative officer in charge of a business, government, or school unit or operation.

Trade off: (a) A balancing of factors all of which are not attainable at the same time. (b) A giving up of one thing in return for another.

Engineering Design Process

An engineering design process is a process used by engineers to help develop products. The Accreditation Board for Engineering and Technology defines the engineering design as:

... a process of devising a system, component or process to meet desired needs. It is a decision making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.

This process can be divided up into a ten-step process, which includes identifying a need, defining the problem, conducting research, narrowing the search, analyzing set criteria, finding alternative solutions, analyzing possible solutions, making a decision, presenting the product, and communicating and selling the product.

The first step of this process is the identification of a need. The engineers themselves often do not identify a need, but rather society discovers a need and then presents that need to the engineering firm. The term "need" is fairly vague, but often refers to desire or shortage of a good. This "need" can sometimes be considered necessity to some people.

The second step of engineering design process is defining the problem. Engineers must appropriately define the problem first, in order to improve it. Solving an insignificant problem can cost a firm millions in funding and precious time.

The third step in the process is research. Most of an engineer's productive time will be spent on research, locating, applying, and transferring information. They first must be well acquainted with as much

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information possible, which in turn produce a better solution. Here the engineer asks many questions, such as, "what has been written about it? Is something already on the market that may solve the problem? What is wrong with the way it is being done? What is right with the way it is being done? Who manufactures the current solution? How much does it cost? Will people pay for a better one if it costs more? How much will they pay (or how bad is the problem)?" All these questions will help the engineer get a better grasp on the problem at hand.

Another major part of this research step is determining the source of information. It is the engineer's job to sift through all of the gathered research and decide what is relevant. One source available is an already existing solution. Reverse engineering is an effective learning technique if other solutions are available on the market. Other effective sources of information include the internet, local libraries, available government documents, personal organizations, trade journals, vendor catalogs and individual experts available. It is very important to record these findings in a bibliography; that way it will be easy to find the information at a later date.

The next step, step four, is to put limitations or constraints on the research. Up until now, the problem research and the definitions have been kept broad to allow for a large amount of possible solutions. Constraints are necessary because they eliminate any extreme solutions that would be inefficient, costly, and physically impossible to create.

The criteria, or "characteristics have to be established from experience, research, market studies and customers preferences that are desired by the consumer. In this step, solutions are compared on a qualitative basis such as appearance, durability and cost. The importance of each characteristic must be agreed upon by the team of engineering in order to find the top reasonable solutions to the problem.

Step six is finding alternative solutions. Here, a list of the possible solution is made and the pros and cons of each solution are discussed. Engineers will sometimes create a checklist of characteristics of the possible solution and decide what could be changed to improve the final result. Brainstorming is a great way to decide what is good about the solution and what could be changed to improve the solution.

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In the next step, all possible alternative solutions have to be analyzed to determine their potential. At this point the engineer will again condense the possible solutions. Using mathematical and key engineering principles, the engineer analyzes the potential performance of the solution to determine if the solution is physically possible, During this analyzing process engineers review the laws of nature and determine whether the product is economically practical by using plain common sense.

Step eight is the decision making step. Some decisions are easily made through analyzing and constraining from the previous step, but at other times the decision on which solution to choose can be close to impossible. What makes decision making so tough is the trade offs of choosing one solution over the other. Often engineers can come up with impeccable solutions, detailing the strengths and weaknesses of all solutions, but in the end cannot make the decision of which is better on their own. One tool that can be helpful in the decision making process is to be organized. Having as much information possible about all the alternative solutions will make it easier to evaluate the product efficiently. Another crucial tool is to have objective for the problem and important criteria clear in mind. Frequently when working on a problem, an engineer may get side tracked, so it is important to remember the purpose of the solution.

In presenting the product in step nine, details about the product can be given visually through sketches. It is important to have accurate sketches in order to describe your ideas to technicians and drafters. Successful engineers will have to communicate accurately through "written, spoken and graphical" languages in order to develop and interpret specifications.

The final step is the *communicating and selling the product* step. Here the engineer has to sell and explain the product in a persuading manner. Selling the product takes place all along the design process. Another way of communication is the written reports which may be read by both management and clients. These written reports can vary in formality but usually contain an appropriate cover page, abstract, table of contents, body, conclusion and recommendation, and an appendix. Another common way of communicating the new product is through an oral presentation which presents the information conveniently to the listener. The key to a good oral

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presentation is to be prepared, have good posture, good eye contact and project your voice loud and clearly. It's important that the oral presentation gives enough information to get the idea across to desired audience, but not too much information to become overwhelming and confusing.

Design is the essence of engineer. The purpose of engineering design revolves around our natural instincts as human beings to always strive for more, and that is why engineering is one of the fastest growing careers. Society will always strive for more than available, pushing engineers, designers, and inventors to continuously produce more innovative ideas. Through the engineering design process, engineers are given the tools and guidelines needed to successfully create these innovative ideas.

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Exercise (5) Determine the Persian equivalents of the following terms and expressions.

1-accomplishments دستاوردها 3-acquainted آشنا شده

2-accreditation Board مجمع اعتبار دهنده 4-administrative اداری

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5-aerialists
6-athletes
7-audience
8-customers preferences
9-decision making process
10-engineering principles
11-handicapped
12-impeccable
13-insignificant problem
14-instincts
15-iterative
16-metal-processing
17-oral
18-overwhelming
19-personal organization
20-persuading manner
21-posture
22-presentation
23-promotions
24-pros and cons
25-shortage
26-side tracked
27-strive
28-synthesis
29-tedious
30-trade journals
31-vague
32-vendor
33-versatile

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UNIT 5
MECHANICAL PROPERTIES & PERFORMANCE OF MATERIALS

Special Terms

Bending: The curvature of a beam about its axis under load.

Brittle fracture: A tensile failure without significant plastic deformation of an ordinarily ductile material.

Creep: A slow plastic deformation of a metal under stress especially at high temperature.

Cross section: The section of a body at right angles to its length.

Deflection: A linear measurement of the amount of movement of a structure subjected to a bending moment, shear force or a couple.

Deformation: a change in the shape or dimensions of a body, resulting from stress; strain.

Displacement: A vector quantity specifying a change in position of an item.

Ductility: Permanent deformation before fracture.

Elasticity modulus: Stress per unit strain.

Fracture: The Propagation of a crack through a material, usually due to repeated application of a load.

Hardness: Resistance to penetration.

Material: Substance from which something else is or can be made.

Mechanical properties: Characteristics of a material in response to externally applied forces.

Notch: A geometric discontinuity in a material which is visible using pure optical methods. This type of discontinuity is of macro proportion 10 μm to 40 μm.

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Specimen: (a) A part or an individual taken as exemplifying a whole mass or number. (b) A sample of a substance or material for examination or study.

Steel: Iron base alloys, commonly containing carbon.

Strain: Deformation from an applied stress.

Stress: Force per unit area.

Tension: (a) The act of stretching or straining. (b) The longitudinal deformation of an elastic body that results in its elongation. (c) The force producing such deformation.

Work hardening: An increase in strength and hardness of metals produced by making them do work, such as resisting stretching or forming. It is most pronounced when cold-working metals such as iron, copper, aluminum and nickel which do not recrystallize at room temperature.

Yield strength: The stress necessary to produce a given inelastic strain in a material.

Mechanical Properties and Performance of Materials

Samples of engineering materials are subjected to a wide variety of mechanical tests to measure their strength, elastic constants, and other material properties as well as their performance under a variety of actual use conditions and environments. The results of such tests are used for two primary purposes: **1)** engineering design (for example, failure theories based on strength, or deflections based on elastic constants and component geometry) and **2)** quality control either by the materials producer to verify the process or by the end user to confirm the material specifications.

Because of the need to compare measured properties and performance on a common basis, users and producers of materials use standardized test methods such as those developed by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO). ASTM and ISO are but two of many standards-writing professional organization in the world. These standards prescribe the method by which the test specimen will be prepared and tested, as well as

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how the test results will be analyzed and reported. Standards also exist which define terminology and nomenclature as well as classification and specification schemes.

The following sections contain information about mechanical tests and a general purpose test equipment called universal testing machine.

Mechanical tests (as opposed to physical, electrical, or other types of tests) often involve the deformation or breakage of samples of material (called test specimens or test pieces). Some common forms of test specimens and loading situations are shown in Figure 5.1. Note that test specimens are nothing more than specialized engineering components in which a known stress or strain state is applied and the material properties are inferred from the resulting mechanical response. For example, strength is nothing more than a stress "at which something happens" be it the onset of nonlinearity in the stress-strain response for yield strength, the maximum applied stress for ultimate tensile strength, or the stress at which specimen actually breaks for the fracture strength,

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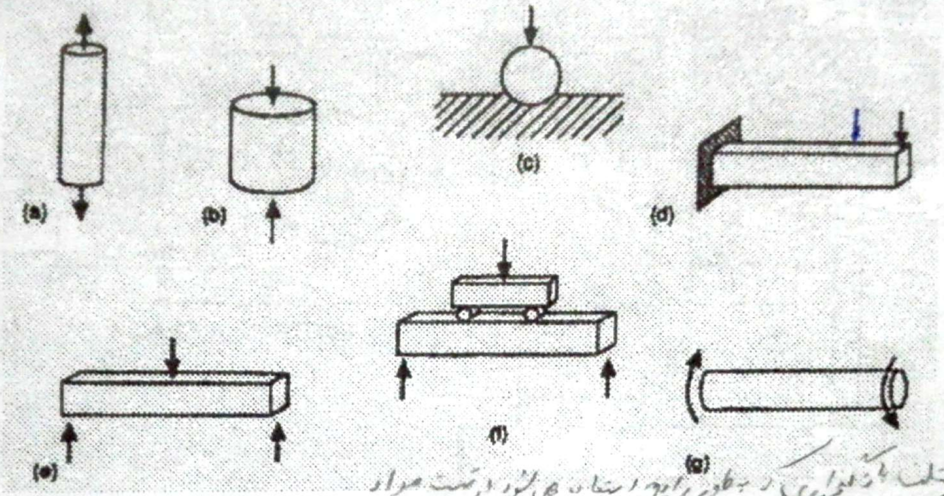

Figure 5.1) Geometry and loading scenarios commonly employed in mechanical testing of materials. a) tension, b) compression, c) indentation hardness, d) cantilever flexure, e) three-point flexure, f) four-point flexure and g) torsion.

Design of a test specimen is not a trivial matter. However, the simplest test specimens are smooth and unnotched. More complex geometries can be used to produce conditions resembling those in actual engineering components. Notches (such as holes, grooves or slots) that have

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a definite radius may be machined in specimens. Sharp notches that produce behavior similar to cracks can also be used, in addition to actual cracks that are introduced in the specimen prior to testing.

Equipments used for mechanical testing range from simple, hand-actuated devices to complex, servo-hydraulic systems controlled through computer interfaces. Common configurations (for example, as shown in Figure 5.2) involve the use of a general purpose device called a universal testing machine. Modern test machines fall into two broad categories: electro (or servo) mechanical (often employing power screws) and servo hydraulic

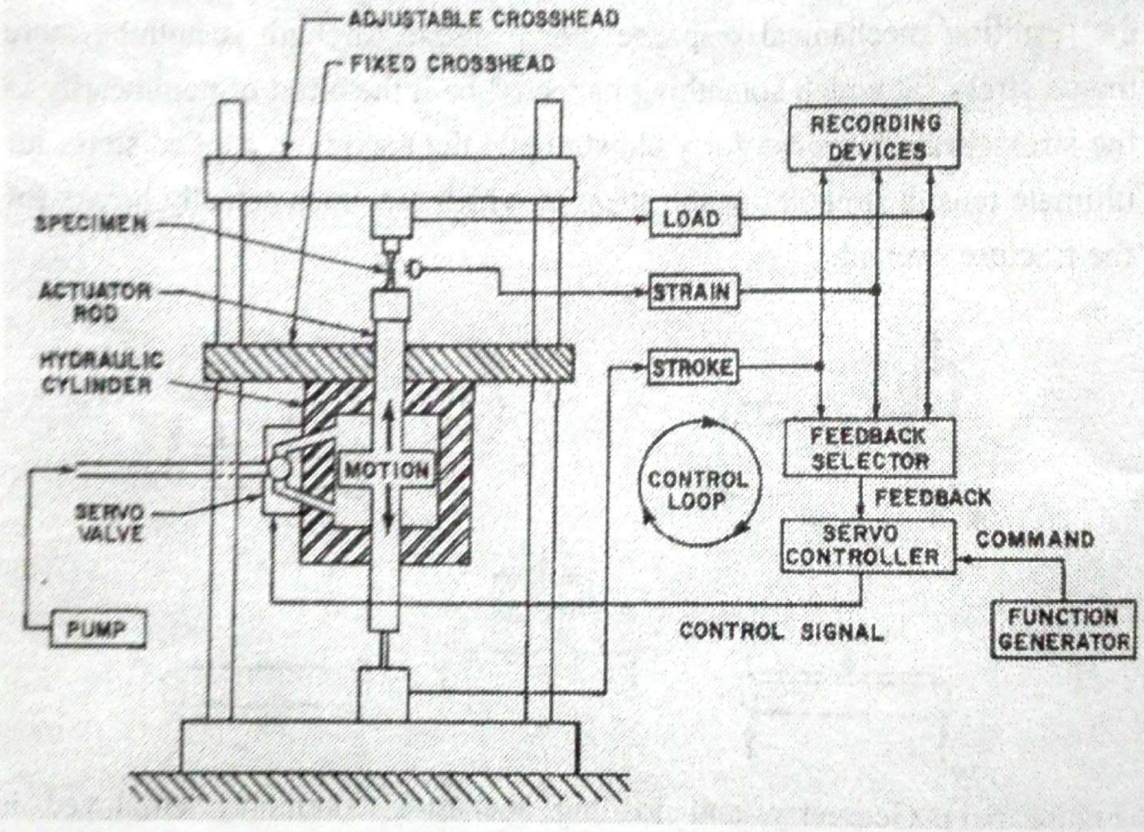

Figure 5.2) Example of a modern, closed-loop servo-hydraulic universal test machine.

(high-pressure hydraulic fluid in hydraulic cylinders). Digital, closed loop control (e.g., force, displacement, strain, etc.) along with computer interfaces and user friendly software are common. Various types of sensors are used to monitor or control force (e.g., strain gauge-based "load" cells), displacement (e.g., linear variable differential transformers (LVDT's) for stroke of the test

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machine), and strain (e.g., clip-on strain-gauge based extensometers). In addition, controlled environments can also be applied through self-contained furnaces, vacuum chambers, or cryogenic apparati. Depending on the information required, the universal test machine can be configured to provide the control, feedback, and test conditions unique to that application.

The tension test is the commonly used test for determining "static" (actually quasi-static) properties of materials. Results of tension tests are tabulated in handbooks and, through the use of failure theories, these data can be used to predict failure of parts subjected to more generalized stress states. Theoretically, this is a good test because of the apparent simplicity with which it can be performed and because the uniaxial loading condition results in a uniform stress distribution across the cross section of the test specimen. In actuality, a direct tensile load is difficult to achieve (because of misalignment of the specimen grips) and some bending usually results. This is not serious when testing ductile materials like copper in which local yielding can redistribute the stress so uniformity exists; however, in brittle materials local yielding is not possible and the resulting non uniform stress distribution would cause failure of the specimen at a load considerably different from that expected if a uniformly distributed load were applied.

The typical stress-strain curve normally observed in text books with some of the common nomenclature is shown in Figure 5.3. This is for a typical low-carbon steel specimen. Note that there are a number of definitions of the transition from elastic to plastic behavior. A few of these definitions are shown in Figure 5.3. Oftentimes the yield point is not so well defined as for this typical steel specimen. Another technique for defining the beginning of plastic behavior is to use an offset yield strength defined as the stress resulting from the intersection of a line drawn parallel to the original straight portion of the stress strain curve, but offset from the origin of this curve by some defined amount of strain, usually 0.1 percent ($\varepsilon = 0.001$) or 0.2 percent ($\varepsilon = 0.002$) and the stress-strain curve itself. The total strain at any point along the curve in Figure 5.3 is partly plastic after yielding begins. The amount of elastic strain can be determined by unloading the specimen at some deformation, as at point A. When the load is removed, the specimen shortens by an amount equal to the stress divided by elastic modulus

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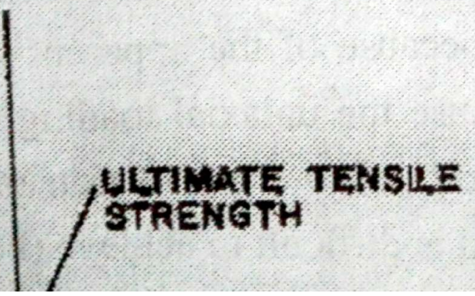
(Young's modulus). This is, in fact, the definition of Young's modulus ($E = \Delta\sigma/\Delta\varepsilon$) in the elastic region.

Other materials exhibit stress-strain curves considerably different from carbon-steel although still highly nonlinear. In addition, the stress-strain curve for more brittle materials, such as cast iron, fully hardened high-carbon steel, or fully work-hardened copper show more linearity and much less nonlinearity than ductile materials. Little ductility is exhibited with



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Exercise (4) Translate the following passage into Persian

Creep

Creep is the term used to describe the tendency of a material to move or to deform permanently to relieve stresses. Material deformation occurs as a result of long term exposure to levels of stress that are below the yield or ultimate strength of the material. Creep is more severe in materials that are subjected to heat for long periods and near melting point. Creep is a monotonically increasing function of temperature.

The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied load (stress). Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function- for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is not necessarily a failure mode, but is instead a deformation mechanism. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that otherwise may have led to cracking.

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concrete is sometimes welcomed because it relieves tensile stresses that otherwise may have led to cracking.

Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep deformation is "time-dependent" deformation.

The temperature range in which creep deformation may occur differs in various materials. For example, Tungsten requires a temperature in the thousands of degrees before creep deformation can occur while ice formations such as the Antarctic ice cap will creep in freezing temperatures. Generally, the minimum temperature required for creep deformation to occur is 30-40% of the melting point for metals and 40-50% of melting point for ceramics. Virtually any material will creep upon approaching its melting temperature. Since the minimum temperature is relative to melting point, creep can be seen at relatively low temperatures for some materials. Plastics and low melting-temperature metals, including many solders, creep at room temperature as can be seen markedly in old lead hot-water pipes. Planetary ice is often at a high temperature relative to its melting point, and creeps.

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Exercise (5) Determine the Persian equivalents of the following terms and expressions.

1-breakage
2-closed loop
3-cracks
4-cryogenic
5-ductile
6-elastic constants
7-electrical short
8-endurance
9-exposure
10-extensometers
11-failure theories
12-fatigue failure
13-filament
14-furnaces
15-gasoline
16-grooves
17-hand-actuated devices
18-impeller
19-intensity
20-intersection
21-load cells
22-magnitude
23-melting point
24-metallurgists
25-misalignment
26-monotonically
27-nomenclature
28-nonlinearity
29-onset
30-planetary
31-plastic behavior
32-power screws
33-primary creep
34-propagate
35-quasi-static
36-sensors
37-servo-hydraulic
38-slots
39-solders
40-strain gauge
41-strain rate
42-terminology
43-tertiary
44-transformers
45-transition
46-trivial
47-turbine blade
48-ultimate tensile strength
49-uniaxial
50-universal testing machine
51-unnotched
52-user friendly
53-vacuum chambers
54-yieldpoint

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UNIT 6
ENGINEERING THERMODYNAMICS

Special Terms

Absolute zero: A theoretical temperature characterized by complete absence of heat and motion and equivalent to exactly −273.15°C or −459.67°F.

Adiabatic process: Occurring without loss or gain of heat.

Boundary: Something that indicates or fixes a limit or extent.

Caveat: (a) An explanation to prevent misinterpretation. (b) A modifying or cautionary detail to be considered when evaluating, interpreting, or doing.

Conservation of energy: A principle in physics: the total energy of an isolated system remains constant irrespective of whatever internal changes may take place with energy disappearing in one form reappearing in another.

Efficiency: (a): Effective operation as measured by a comparison of production with cost (as in energy, time, and money). (b) The ratio of the useful energy delivered by a dynamic system to the energy supplied to it.

Enthalpy: The heat content per unit mass of a substance.

Entropy: A substance receiving a quantity of heat dQ at temperature T is said to have its entropy increased by dQ/T. Entropy is measured in Joules/K.

Heat engine: Any kind of engine that converts heat into mechanical energy.

Isobaric: Characterized by constant or equal pressure.

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Isometric: Of, relating to, or characterized by equality of measure; *especially* relating to or being a crystallographic system characterized by three equal axes at right angles.

Isothermal process: A process such as the compression or expansion of a gas without any change in temperature.

Macroscopic: (a) Observable by the naked eye. (b) Involving large units or elements.

Shaft: A spindle revolving in bearings and carrying pulleys, gear wheels etc., for the transmission of power. Shafts can be either solid or hollow, the latter giving an improved *torque* carrying capacity for a given shaft weight. They have circular cross-sections where they fit into bearings and *shoulders, collars,* or steps of different diameter for the location of parts mounted on them. Shafts may run concentrically within one another as in a multiple *spool-gas* turbine. Shafts may have a *taper shank* to suit components with a matching taper bore, or vice versa, with a nut or *tang* giving positive location to the assembly, or the shaft may be threaded for rigid attachment of a component.

Substance: (a) Physical material from which something is made or which has discrete existence. (b) Matter of particular or definite chemical constitution.

Work: (a) The overcoming of resistance (force) through a certain distance.

Engineering Thermodynamics

Thermodynamics, derived from the Greek *thermos*, meaning heat; and *dynamics*, meaning power, is a branch of physics that studies the effects of changes in temperature, pressure, and volume on physical systems at the macroscopic scale by analyzing the collective motion of their particles using statistics. Roughly, heat means "energy in transit" and dynamics relates to "movement"; thus, in essence thermodynamics studies the movement of energy and how energy instills movement. Historically, thermodynamics developed out of the need to increase the efficiency of early steam engines.

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The starting point for most thermodynamic considerations are the laws of thermodynamics, which postulate that energy can be exchanged between physical systems as heat or work. They also postulate the existence of a quantity named entropy, which can be defined for any system.

In thermodynamics, there are four laws of very general validity, and as such they do not depend on the details of the interactions or the systems being studied. Hence, they can be applied to systems about which one knows nothing other than the balance of energy and matter transfer. Examples of this include Einstein's prediction of spontaneous emission around the turn of the 20th century and current research into the thermodynamics of black hole. The four laws are:

- Zeroth law of thermodynamics which is about the transitivity of thermodynamic equilibrium. It states that if two thermodynamic systems A and B are in thermal equilibrium, and B and C are also in thermal equilibrium, then A and C are in thermal equilibrium.
- First law of thermodynamics which is the law of conservation of energy. This law says that the increase in the energy of a closed system is equal to the amount of energy added to the system by heating, minus the amount lost in the form of work done by the system on its surroundings. For an infinitesimal process, the first law can be written in the form:

$$dE = dQ - dW$$

where dE is the change in internal energy of the system, dQ is the heat absorbed by the system, and dW is the work done by the system on its surroundings. Note that this is just a convention. We could equally well write the first law in terms of the heat emitted by the system or the work done on the system. It does not really matter, as long as we are consistent in our definitions.

- Second law provides information about entropy. It generally states that the total entropy of any isolated thermodynamic system tends to increase over time, approaching a maximum value. In a mathematical form, for a quasi-static process, the second law implies that:

$$dQ = TdS$$

where T is the thermodynamic temperature, and dS is the change in entropy

of the system.

- Third law of thermodynamics is about absolute zero temperature, stating that as a system approaches absolute zero of temperature all processes cease and the entropy of the system approaches a minimum value or zero for the case of a perfect crystalline substance.

Although there are formally four laws of thermodynamics, the zeroth law is really a consequence of the second law, and the third law is actually only important at temperatures close to absolute zero. Therefore, for most engineering purposes, the two laws which really matter are the first law and the second law.

In thermodynamics, interactions between large ensembles of objects are studied and categorized. Central to this are the concepts of *system* and *surroundings*. A system is the region of the universe under study. A system is separated from the remainder of the universe by a boundary which may be imaginary or not, but which, by convention delimits a finite volume. The possible exchanges of work, heat, or matter between the system and the surroundings take place across this boundary. There are five dominant classes of systems:

1. Isolated Systems – matter and energy may not cross the boundary.
2. Adiabatic Systems – heat may not cross the boundary.
3. Diathermic Systems – heat may cross boundary.
4. Closed Systems – matter may not cross the boundary.
5. Open Systems – heat, work, and matter may cross the boundary.

For closed systems, as time goes by, internal differences in the system tend to even out; pressures and temperatures tend to equalize, as do density differences. A system in which all equalizing processes have gone practically to completion, is considered to be in a state of thermodynamic equilibrium.

In thermodynamic equilibrium, a system's properties are, by definition, unchanging in time. Systems in equilibrium are much simpler and easier to understand than systems which are not in equilibrium. Often, when analyzing a thermodynamic process, it can be assumed that each intermediate state in the process is at equilibrium. This will also considerably simplify the situation. Thermodynamic processes which

develop so slowly as to allow each intermediate step to be an equilibrium state are said to be reversible processes. But what is meant by a thermodynamic process is explained in the following section.

A thermodynamic process may be defined as the energetic evolution of a thermodynamic system proceeding from an initial state to a final state. Typically, each thermodynamic process is distinguished from other processes, in energetic character, according to what parameters, as temperature, pressure, or volume, etc., are held fixed. Furthermore, it is useful to group these processes into pairs, in which each variable held constant is one member of a conjugate pair. The six most common thermodynamic processes are listed below:

1. An isobaric process occurs at constant pressure.
2. An isochoric process, or isometric/isovolumetric process, occurs at constant volume.
3. An isothermal process occurs at a constant temperature.
4. An isentropic process occurs at a constant entropy.
5. An isenthalpic process occurs at a constant enthalpy.
6. An adiabatic process occurs without loss or gain of heat.

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Exercise (4) Translate the following passage into Persian.

Heat engines

Thermodynamics was invented, almost by accident, in 1825 by a young French engineer called Sadi Carnot who was investigating the theoretical limitations on the efficiency of steam engines. Although we are not particularly interested in steam engines, nowadays, it is still highly instructive to review some of Carnot's arguments. We know by observation, that it is possible to do mechanical work w upon a device M, and then to extract an equivalent amount of heat q, which goes to increase the internal energy of some heat reservoir. (Here, we use small letters w and q to denote intrinsically positive amounts of work and heat, respectively.) An example of this is Joule's classic experiment by which he verified the first law of thermodynamics: a paddle wheel is spun in a liquid by a falling weight, and the work done by the weight on the wheel is converted into heat, and absorbed by the liquid. Carnot's question was this: is it possible to reverse this process and build a device, called a heat engine, which extracts heat energy from a reservoir and converts it into useful macroscopic work? For instance, is it possible to extract heat from the ocean and use it to run an electric generator?

There are a few caveats to Carnot's question. First of all, the work should not be done at the expense of the heat engine itself, otherwise the conversion of heat into work could not continue indefinitely. We can ensure that this is the case if the heat engine performs some sort of cycle, by which

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Exercise (5) Determine the Persian equivale[nts of the following]
expressions.

1-absorbed
2-black hole
3-categorized
4-conjugate
5-delimits
6-diathermic
7-emission
8-energetic
9-ensembles
10-even out
11-fantastically
12-imaginary
13-infinitesimal
14-instills
15-instructive
16-interactions
17-intermediate state
18-internal combustion engines
19-internal energy
20-intrinsically

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21-isenthalpic process فرایند با آنتالپی ثابت

22-isochoric process فرایند هم حجم

23-isolated مجزا، جدا

24-isovolumetric = ۲۲

25-jiggling لرزش کوچک - اهتزاز آهسته

26-paddle wheel چرخ پره ای

27-periodically به طور نوبتی

28-randomly به طور تصادفی

29-reservoir سرچشمه ، منبع

30-resistance thermometers ترمومتر مقاومتی

31-reversible processes فرایند برگشت پذیر

32-scenario سناریو

33-single degree of freedom یک درجه آزاد

34-spontaneous خود به خودی

35-surroundings اطراف

36-thermal equilibrium تعادل گرمایی

37-thermocouples ترموکوپل ها

38-torque گشتاور (پیچشی)

39-transitivity تعدد

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Engineering Mechanics

Mechanics is that branch of physical science which deals with the state of rest or motion of bodies under the action of forces. No one subject plays a greater role in engineering analysis than mechanics. The early history of this subject is synonymous with the very beginnings of engineering. Modern research and development in the fields of vibrations, stability and strength of structures and machines, robotics, rocket and spacecraft design, automatic control engine performance, fluid flow, electrical machines and apparatus, and molecular, atomic, and subatomic behavior are highly dependent on the basic principles of mechanics. A thorough understanding of this subject is an essential prerequisite for work in these and many other fields.

Mechanics is one of the oldest physical sciences, dating back to the time of Archimedes (287-212 B.C.). A delightful account of the use of mechanics by Archimedes in the defense of Syracuse against the Romans may be found in *Plutarch's Lives.* As a science, mechanics has intrigued almost all of the great scientists, e.g., Stevin, Galileo, Newton, d'Alembert, Lagrange, Laplace, Euler, Einstein, to name only a few whose names are familiar. It continues to be a fascinating subject by continually expanding its areas of application.

The principles of mechanics as a science embody the rigor of mathematics on which they are highly dependent. Thus, mathematics play an important role in achieving the purpose of engineering mechanics which is the application of these principles to the solution of practical problems. Here we shall be concerned with both the rigorous development of principles and their application. The basic principles of mechanics are relatively few in number, but they have exceedingly wide application, and the methods employed in mechanics carry over into many fields of engineering endeavor.

The subject of mechanics is logically divided into two parts: statics, which concerns the equilibrium of bodies under the action of forces, and dynamics, which concerns the motion of bodies.

Certain concepts and definitions are basic to the study of mechanics, and should be understood at the outset.

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Space is the geometric region occupied by bodies whose positions are described by linear and angular measurements relative to a coordinate system. For three-dimensional problems three independent coordinates are needed. For two-dimensional problems only two coordinates will be required.

Time is the measure of the succession of events and is a basic quantity in dynamics. Time is not directly involved in the analysis of statics problems.

Mass is a measure of the inertia of a body, which is its resistance to a change of velocity. Mass can also be regarded as the quantity of matter in a body. Of more importance to us in statics, mass is also the property of every body by which it experiences mutual attraction to other bodies.

Force is the action of one body on another. A force tends to move a body in the direction of its action. The action of a force is characterized by its magnitude, by the direction of its action, and by its point of application. Force is a vector quantity.

Particle. A body of negligible dimensions is called a particle. In the mathematical sense a particle is a body whose dimensions approach zero so that it may be analyzed as a point mass. Frequently a particle is chosen as a differential element of a body. Also, when the dimensions of a body are irrelevant to the description of its position or the action of forces applied to it, the body may be treated as a particle.

Rigid body. A body is considered rigid when the relative movements between its parts are negligible for the purpose at hand. For instance, the calculation of the tension in the cable which supports the boom of a mobile crane under load is essentially unaffected by the small internal strains (deformations) in the structural members of the boom. For the purpose, then, of determining the external force which acts on the boom, we may treat it as a rigid body. Statics deals primarily with the calculation of external forces which act on rigid bodies which are in equilibrium. To determine the internal stresses and strains, the deformation characteristics of the boom material would have to be analyzed. This type of analysis belongs to the study of the mechanics of deformable bodies, which comes after the study of statics.

Mechanics deals with two kinds of quantities: scalars and vectors.

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Scalar quantities are those with which a magnitude alone is associated. Examples of scalar quantities in mechanics are time, volume, density, speed, energy, and mass. Vector quantities, on the other hand, possess direction as well as magnitude and must obey the parallelogram law of addition as described in here. Examples of quantities by vectors are displacement, velocity, acceleration, force, moment, and momentum.

Physical quantities represented by vectors fall into one of the following three classifications

- *Free*
- *Sliding*
- *fixed*

A free vector is one whose action is not confined to or associated with a unique line in space. For example, if a body moves without rotation, then the movement or displacement of any point in the body may be taken as a vector, and this vector will describe equally well the direction and magnitude of the displacement of every point in the body. Hence, we may represent the displacement of such a body by a free vector.

A fixed vector is one for which a unique point of application is specified, and therefore the vector occupies a particular position in space. The action of a force on a deformable or non-rigid body must be specified by a fixed vector at the point of application of the force. In this problem the forces and deformations internal to the body will be dependent on the point of application of the force, as well as its magnitude and line of action.

Exercise (1) Answer the following questions

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Exercise (5) Determine the Persian equivalents of the following terms and expressions.

1-abbreviated اختصاری شده

2-apparatus

3-astronomical

4-boom

5-classifications

6-commerce

7-coordinate system دستگاه مختصات

8-crane جرثقیل

9-endeavor تلاش و کوشش بسیار زیاد، سعی

10-fundamental بنیادی، ریشه ای

11-parallelogram law قانون متوازن الأضلاع

12-prerequisite لازمه

13-rectangular axes محورهای مستطیلی

14-reference frame محور مرجع

15-rigor سختی - دقت

16-spacecraft فضا پیما

17-stability پایداری

18-synonymous مترادف

19-trajectories مسیر، خط سیر

20-translation حرکت انتقال - جابجایی - ترجمه

21-unique منحصر به فرد

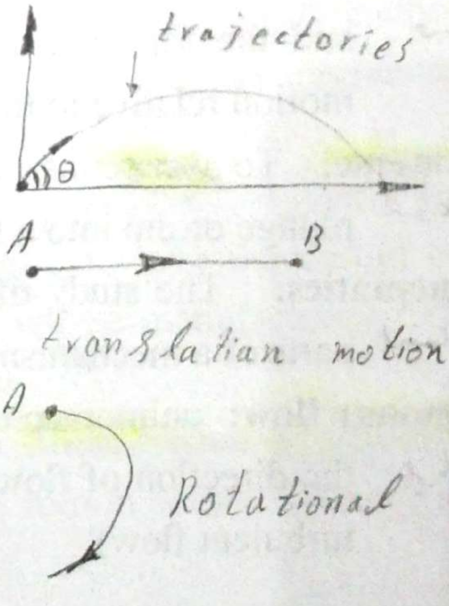
۲- وسایل

۳- نجومی

۴- بازوی متحرک جرثقیل - پیشرفت ناگهانی - غرش

۵- طبقه بندی

۶- تجارت



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UNIT 10

FLUID POWER SYSTEMS

Special Terms

Accumulator: A device (as in a hydraulic system) in which a fluid is collected and especially in which it is kept under pressure as a means of storing energy.

Actuator: A mechanical device for moving or controlling something.

Aerosol: (a) A suspension of fine solid or liquid particles in gas. (b) A substance (as an insecticide or medicine) dispensed from a pressurized container.

Hazardous: Involving or exposing one to risk (as of loss or harm).

Hose: A flexible tube for conveying a fluid, gas or slurry.

Hydraulics: A branch of science that deals with practical applications (as the transmission of energy or the effects of flow) of liquid (as water) in motion.

Jackhammer: (a) A pneumatically operated percussive rock-drilling tool usually held in the hands. (b) A device in which a tool (as a chisel for breaking up pavements) is driven percussively by compressed air.

Jerkiness: (a) Moving along with or marked by fits and starts. (b) Characterized by abrupt transitions.

Patent: Protected by a trademark or a brand name so as to establish proprietary rights analogous to those conveyed by a patent.

Plumbing: (a) The apparatus (as pipes and fixtures) concerned in the distribution and use of water in a building. (b) An internal system that resembles plumbing; especially one consisting of conduits or

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channels for conveying fluids.

Pneumatic: Of, relating to, or using gas (as air or wind).

Pressure: The force or thrust exerted over a surface divided by its area.

Pump: A device that raises, transfers, delivers, or compresses fluids or that attenuates gases especially by suction or pressure or both.

Ratchet: A mechanism that consists of a bar or wheel having inclined teeth into which a pawl drops so that motion can be imparted to the wheel or bar, governed, or prevented and that is used in a hand tool (as a wrench or screwdriver) to allow effective motion in one direction only.

Rotary: Turning on an axis like a wheel.

Sandblasting: The cleaning of a metal surface by a high-velocity jet of sand or an abrasive material, sometimes called shot-blasting.

Transducer: A device for converting a physical quantity (or signal) of one kind into another kind.

Torque: The turning moment about an axis, for example, of the air forces on a propeller, which may be uniform or fluctuating or of the turning moment of an engine crankshaft.

Valve: A lid or cover to an aperture that opens a communication for a liquid or gas in one direction or closes it in another, or regulates the amount of flow, either manually or automatically.

Wrench: A hand or power tool for holding, twisting, or turning an object (as a bolt or nut).

Fluid Power Systems

The term fluid power refers to energy that is transmitted via a fluid under pressure. The use of fluids to transmit energy goes back hundreds of years, to times when windmills were used to grind corn and waterwheels were used to drive pumps and early forms of machinery. Waterwheels of various types simply converted the kinetic energy of flowing water, or the potential energy of differing levels, into rotary motion.

With hydraulics, the working fluid is liquid such as oil or water, whereas, with pneumatics, the fluid is typically compressed air or inert gas.

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Fluid power's motive force comes from the principle that pressure applied to a confined fluid is transferred uniformly and undiminished to every portion of the fluid and to the walls of the container that holds the fluid. A surface such as a cylinder piston will move if the difference in force across the piston is larger than the total load plus frictional forces. The resulting net force can then accelerate the load proportional to the ratio of the force divided by the mass.

Although hydraulic and pneumatic power systems share many characteristics in common, there are some key differences. For example, because hydraulic fluid is much less compressible than a gas, hydraulic power is preferred over pneumatic when precise position control is required. On the other hand, pneumatic power has an edge in applications where the presence of hydraulic oil could cause problems (e.g. in food processing machines). Pneumatic systems are also typically less expensive to build than hydraulic.

The design of a hydraulic or pneumatic power circuit and selection and physical placement of the components in the system are critical to maximizing the performance of fluid power systems. Figure 10-1 shows a typical hydraulic system with electronic motion controller. Following is a discussion of key system elements.

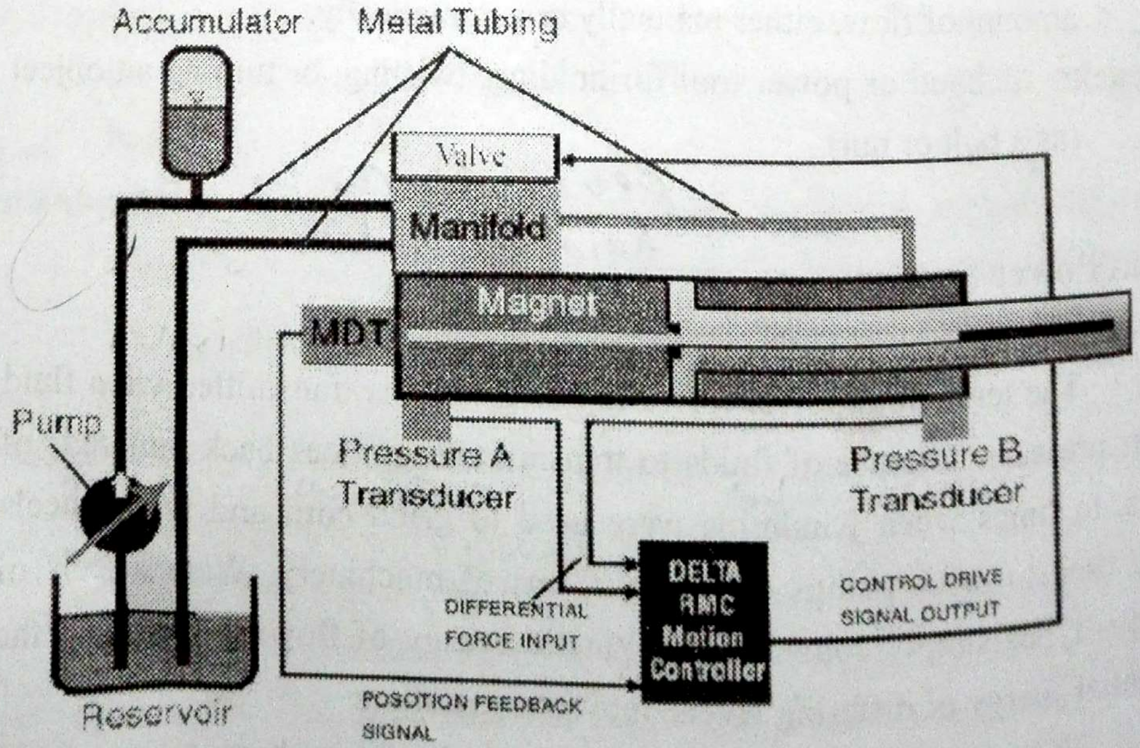

Figure 10-1) A typical hydraulic system.

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Exercise (5) Determine the Persian equivalents of the following terms and expressions.

1-air brake
2-air sirens
3-atomizing
4-bypassed
5-crank
6-dead zone
7-differential
8-discrete
9-dispenser
10-food processing
11-gains
12-homing
13-inert
14-interference
15-intermittent
16-lug nuts
17-magnetostricive
18-motion controller
19-motive force
20-natural frequency
21-nozzle
22-oscillating
23-overheat
24-oversized
25-peak loads
26-PID
27-placement
28-position control
29-pre-charged
30-precise
31-pressure drops
32-productivity
33-smart functions
34-smooth
35-sophisticated
36-sucked up
37-target position
38-undersized
39-undiminished
40-waterwheels
41-zero-overlap

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UNIT 13
HEAT TRANSFER

Special Terms

Air conditioning: To equip (as a building) with an apparatus for washing air and controlling its humidity and temperature.

Boundary layer: A region of retarded fluid near the surface of a body which moves through a fluid or past which a fluid moves.

Buoyancy: (a) The tendency of a body to float or to rise when submerged in a fluid. (b) The power of a fluid to exert an upward force on a body placed in it.

Condenser: A chamber into which exhaust steam from a steam engine or turbine is condensed; a high degree of vacuum is maintained by an air pump.

Conduction: The transfer of heat through matter by communication of kinetic energy from particle to particle with no net displacement of the particles.

Convection: The circulatory motion that occurs in a fluid at a non-uniform temperature owing to the variation of its density and the action of gravity.

Emissivity: (a) The relative power of a surface to emit heat by radiation. (b) The ratio of the radiant energy emitted by a surface to that emitted by a blackbody at the same temperature.

Fins: (a) Thin projecting strips of metal on air-cooled piston engine cylinders to increase the cooling area. (b) Any thin projecting edges on a metal pice.

Heat exchanger: A device for transferring heat from one medium to another often through metal walls, usually to extract heat from a

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medium flowing between two surfaces.

Insulator: a material that is a poor conductor (as of electricity or heat).

Radiation: The transmission of energy by waves.

Refrigeration: Process of producing low temperatures.

Turbulance: (a) Irregular atmospheric motion especially when characterized by up-and-down currents. (b) Departure in a fluid from a smooth flow.

Heat Transfer

Heat transfer is the science that seeks to predict the energy transfer that may take place between material bodies as a result of a temperature difference. Thermodynamics teaches that this energy transfer is defined as heat. The science of heat transfer seeks not merely to explain how heat energy may be transferred, but also to predict the rate at which the exchange will take place under certain specified conditions. The fact that a heat-transfer rate is the desired objective of an analysis points out the difference between heat transfer and thermodynamics. Thermodynamics deals with systems in equilibrium; it may be used to predict the amount of energy required to change a system from one equilibrium state to another; it may not be used to predict how fast a change will take place since the system is not in equilibrium during the process. Heat transfer supplements the first and second principles of thermodynamics by providing additional experimental rules which may be used to establish energy-transfer rates. As in the science of thermodynamics, the experimental rules used as a basis of the subject of heat transfer are rather simple and easily expanded to encompass a variety of practical situations. There are three physical mechanisms by which heat can flow from a system to its surroundings: conduction, convection and radiation.

Conduction is a mode of heat transfer that occurs when there is a temperature gradient across a body. In this case, the energy is transferred from a high temperature region to low temperature region due to random molecular motion - diffusion. Higher temperatures are associated with higher molecular energies and when they collide with less energetic

molecules the transfer of energy occurs.

The simplest conduction heat transfer can be described as "one dimensional heat flow" depicted in Figure 13-1. In this situation, the heat flows into one face of the object and out the opposite face with no heat loss (flow) out the sides of the object. The surfaces 1 and 2 are held at constant temperature. Clearly, "in one dimensional heat flow," the temperature of an object is a function of only one variable, namely the distance from either face of the object (face 1 or 2).

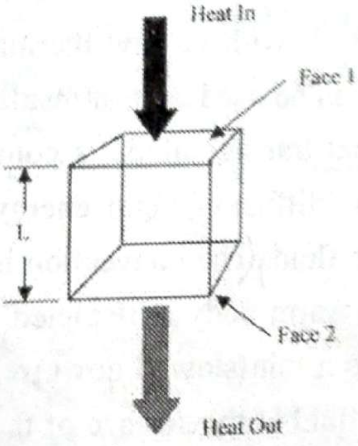

Figure 13-1) One dimensional conductive heat flow.

The heat transfer rate by conduction can be expressed as:

$$Q = -\frac{kA}{L}(T_2 - T_1) \qquad (1)$$

Equation (1) is the Fourier law of heat conduction for flat surfaces, in which T_1 and T_2 are the temperatures of the two faces of the object (see Figure 13-1). A is the surface area of the object normal to heat flow, and L is its thickness. It states that the energy transferred by conduction is directly proportional to surface area and temperature gradient and inversely proportional to L. The negative sign is introduced to account for the fact that energy is conducted in the direction of decreasing temperature. The constant of proportionality k is called the *thermal conductivity*. The value of k will be different for different substances. For a given substance, it will be

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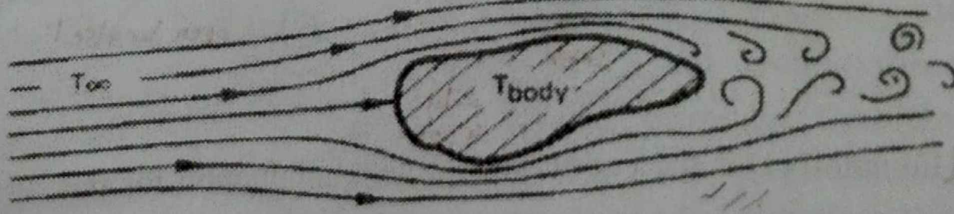
a function of the temperature of the substance, (some increasing with temperature (e.g., water, air), others decreasing with temperature (e.g., oil, most metals). Metals have the largest values of thermal conductivity. The best thermal conductors are generally the best electrical conductors. The thermal conductivity of fluids is very low, so that the heat transferred in totally still liquids and gases is very small in comparison with the augmentation in heat transfer due to the convective motion of the fluid. For example, if air is confined in very small spaces and hence is restrained from circulating, as in the pores of corkboard or wool clothing, convection heat transfer is inhibited. Since air with its low thermal conductivity is a poor conductor, such materials can be used as heat insulators.

The *convection* heat transfer mode is comprised two mechanisms: random molecular motion (diffusion), and energy transferred by bulk or macroscopic motion of the fluid. The convection heat transfer occurs when a cool fluid flows past the warm body as depicted in Figure 13-2. The fluid adjacent to the body forms a thin slowed down region called the boundary layer. The velocity of the fluid at the surface of the body is reduced to zero due to the viscous action. Therefore, at this point, the heat is transferred only by conduction. The moving fluid then carries the heat away. The temperature gradient at the surface of the body depends on the rate at which the fluid carries the heat away.



(Figure 13-2) Convective cooling of a heated body.

Newton's law of cooling expresses the overall effect of convection:

$$\dot{Q} = hA(T_w - T_\infty) \qquad (2)$$

where A is the surface area, T_w is the wall (surface) temperature and T_∞ is

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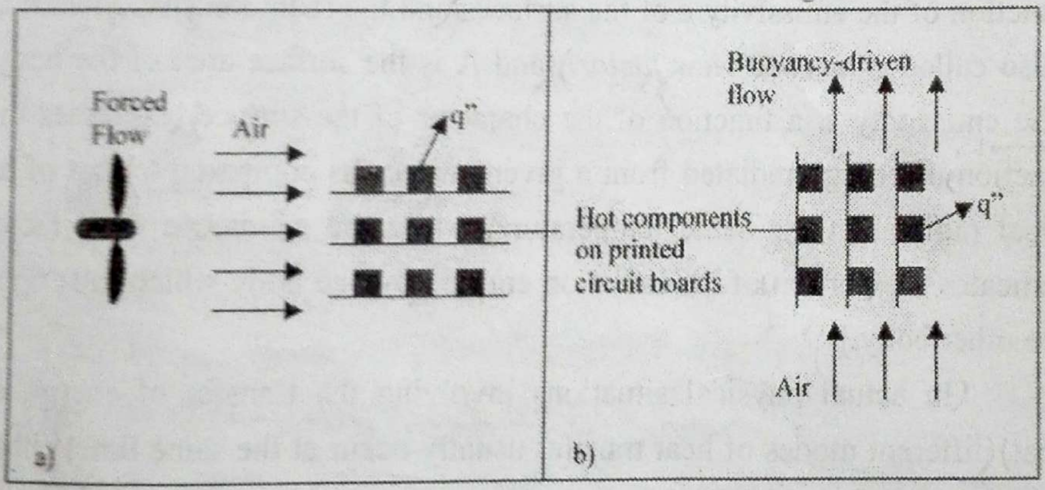
the fluid temperature. The constant of proportionality h is called the convective heat transfer coefficient. This constant, usually determined experimentally, will in general be a function of the configuration and size of the body, the temperature of the fluid and of the body's surface, the velocity of the fluid, and physical properties of the fluid (particularly the thermal conductivity k).

The convection heat transfer may be classified according to the nature of fluid flow. Forced convection occurs when the flow is caused by external means, such as a fan, a pump and similar. An example is a fan which provides forced convection air cooling of hot electrical components on a printed circuit board as depicted in Figure 13-3(a).



(Figure 13-3) Convection heat transfer process. (a) Forced convection, (b) Natural convection.

In contrast, for the natural (or free) convection, the flow is induced by buoyancy forces which arise from density differences caused by temperature variations in the fluid. An example is the free convection heat transfer that occurs from hot components on a vertical array of printed circuit boards in still air as depicted in Figure 13-3b. In such situation, air that makes contact with the hot components experiences an increase in temperature and therefore reduction in density. Since the warm air is now lighter than surrounding air, buoyancy forces induce a vertical motion and the hot air rising from the boards is replaced by the inflow of air at room temperature.

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The third way to transfer heat, in addition to convection and conduction, is by *radiation.* All bodies emit energy by means of electromagnetic radiation. The electromagnetic radiation propagated as a result of a temperature difference is called thermal radiation. The amount of heat transferred by radiation between two bodies at different surface temperatures T_1 and T_2 will be proportional to the difference of the fourth power of the absolute temperatures of each body:

$$\dot{Q} = F(\varepsilon, G)A(T^4{}_1 - T^4{}_2) \qquad (3)$$

where the constant F(ε , G) is called the *radiation factor,* which is a function of the emissivity ε of the surfaces and the radiation shape factor G (also called *geometric view factor*) and A is the surface area of the body. The emissivity ε, a function of the character of the surface, expresses the fraction of energy radiated from a given surface as compared to that of an ideal radiator at the same temperature, while the geometric view factor indicates the portion of the radiation emitted by one body which falls upon the other body.

In actual physical situations involving the transfer of energy as heat, different modes of heat transfer usually occur at the same time, either in series such as convection and conduction in a refrigeration condenser or in parallel such as convection and radiation from a bare, high-temperature metal pipe to room air.

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condenser as a high-pressure liquid at roughly outside air temperature. It then flows through a narrowing in the pipe into the evaporator. When the fluid goes through the narrowing in the pipe, its pressure drops and it enters the evaporator as a low-pressure liquid. The cycle repeats. Overall, heat is extracted from the room and delivered to the outside air. The compressor consumes electric energy during this process, which turns into thermal energy in the outside air.

Exercise (5) Determine the Persian equivalents of the following terms and expressions.

1-adjacent
2-augmentation
3-buoyancy forces
4-coefficient
5-collide
6-compressor
7-configuration
8-convective
9-corrugations
10-counter-flow
11-cross-flow
12-emit
13-encompass
14-evaporator
15-extracted
16-forced convection
17-geometric view factor
18-inversely proportional
19-natural (or free) convection
20-parallel-flow
21-pores
22-printed circuit board
23-radiation factor
24-snake-like pipe
25-squeezing
26-temperature gradient
27-thermal conductivity
28-viscous

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